Army Research Laboratory

Tactile Displays and Detectability of Vibrotactile Patterns as Combat Assault Maneuvers are Being Performed

by Andrea S. Krausman and Timothy L. White

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14. ABSTRACT

This study examined the issues related to tactile displays and the detectability of vibrotactile patterns as combat assault maneuvers were being performed. Three obstacles were used in this study: tires, windows, and high crawl. A baseline condition, in which participants received tactile patterns while standing, was also included in the analysis. In the baseline condition, participants detected and identified 100% of the tactile patterns. Analysis of the obstacle data showed that the obstacles had a significant effect on the detection and identification of the tactile signals. Participants detected 62.5% of the tactile patterns during the high crawl, which was significantly lower than for the tires and windows, with 92% and 88% of signals detected, respectively. With regard to the correct identification of tactile patterns, participants correctly identified 51% of the patterns during the high crawl, as compared to 88.5% for the tires and 77% for the windows. There were no significant differences in the response times.

15. SUBJECT TERMS

human factors; tactile; tactile displays; vibrotactile

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1. Background

The skin is the body's largest organ, yet it is the most underused sense for displaying information in human-computer interfaces (Brewster & Brown, 2004). Our sense of touch can be both informative and intuitive. For example, a tap on the shoulder instinctively tells you that someone is behind you, his or her location, and that s/he wants your attention (Castle & Dobbins, 2004). The skin shows potential as an effective medium to communicate information, which has led to the development of tactile displays.

Tactile displays have existed for several years, but it is only recently that their potential has been explored. Empirical evidence suggests that tactile displays are an effective method of alerting pilots about possible threats or other situations that may occur during a mission, especially when the visual channel is already overloaded or unavailable (Gilliland & Schlegel, 1994). Tactile displays are also promising for navigation tasks (Jones & Nakamura, 2003; van Erp, 2005; Elliott, Redden, Krausman, Carstens, & Pettitt, 2005) and as an aid for pilots experiencing sensory disorientation while flying (Raj, Kass, & Perry, 2000). There are several inherent advantages to tactile displays, namely, tactile messages are silent, yet can be perceived by the user, and tactile displays provide an alternate information channel for those situations when the use of visual or auditory displays is not practical (van Veen & van Erp, 2003).

Although vibrotactile displays are becoming increasingly common in everyday devices such as mobile phones, pagers, and game controllers, the vibrations used in these devices do not fully capture the potential of vibration as a means of communicating (Brewster & Brown, 2004). Encoding information into tactile patterns or "tactons" may be a method of exploiting the benefits of vibrotactile technology as a communication medium. An area of particular interest to the military is using tactile patterns to relay information to the Soldier. For example, military hand signals, if translated into tactile patterns, would allow their visual channel to remain free and allow Soldiers to maintain greater distances from one another. In one study, Pettitt, Redden, and Carstens (2006) evaluated Soldiers' abilities to interpret and respond to tactile and visual hand signals. Participants received tactile and visual hand and arm signals as they negotiated an individual movement techniques (IMT) course while wearing their standard uniforms and body armor. Tactile signals were presented via a belt worn around the waist, which contained eight tactors spaced at equivalent points. Results demonstrated that Soldiers were able to receive, interpret, and accurately respond to the tactile commands faster than to the conventional hand and arm signals. Soldiers also commented they were better able to focus more attention on negotiating obstacles and on area situation awareness (SA) when receiving tactile signals than when maintaining visual contact with their leaders in order to receive standard hand and arm signals. Jones, Lockyer, and Piateski (2006) investigated the ability of participants to recognize and respond to tactile navigation patterns presented to the lower back. In their study, participants were able to recognize and correctly respond to the patterns with almost perfect accuracy. Results of these studies suggest that tactile patterns may be an effective means of communicating information to the Soldier. However, one issue that has not been adequately addressed in the literature is how different types of tactile displays affect tactile pattern recognition, especially when we consider the types of tasks that Soldiers perform during combat operations. The goal of the present study is to investigate these issues.

2. Objective

The objectives explored within this study were to determine

(a) how the configuration of tactile displays affects the detection and recognition of tactile patterns.

Hypothesis: Detection and correct identification of tactile patterns with the back display will be superior to the belt display because the back display uses a 4x4 array of tactors that provides a degree of redundancy.

(b) to what extent different combat maneuvers affect the detection and recognition of tactile patterns.

Hypothesis: Maneuvers that require more body movement will affect detection and recognition of tactile patterns.

(c) how wearing body armor with small arms protective insert (SAPI) plates affects the detection and recognition of tactile patterns.

Hypothesis: The weight of the body armor pressing on the tactors in the belt and back display will make detection and identification of tactile patterns difficult.

(d) if any of the six tactile patterns have higher identification rates.

Hypothesis: Identification rates will be similar for the six tactile patterns.

3. Method

3.1 Participants

Ten non-commissioned officers (NCOs) volunteered to participate in this study. Participants were from the 11C military occupational specialty (MOS) from Fort Stewart, Georgia. All participants were free from any injury or medical problem that would preclude them from participating. The voluntary, fully informed consent of the persons used in this research was obtained as required by 32 Code of Federal Regulations (CFR) 219 and Army Regulation (AR) 70-25. The investigators adhered to the policies for the protection of human subjects as prescribed in AR 70-25. Participants did not receive monetary compensation for their participation and were free to withdraw from the study at any time without penalty. A coding scheme was used to identify the data by participant number only (e.g., Subject 1) to maintain confidentiality. All photographs taken during the course of the study were modified to ensure that participants could not be identified.

3.2 Instrumentation

3.2.1 500-meter Mobility-Portability Course (Known Distance [KD] Range)

The mobility-portability course (see figure 1) consists of 19 individual obstacles spread over a twisting course about 500 meters long. The obstacles have been chosen to subject the participants to the kinds of maneuvers they should expect to perform in combat, such as running, jumping, climbing, balancing, negotiating buildings, stairs, windows, and crawling. For the purposes of this study, three obstacles were used: tires (see figure 2), windows (see figure 3), and high crawl (see figure 4). These obstacles were chosen because they provide ample time for several tactile patterns to be sent and are most likely to interfere with pattern perception.

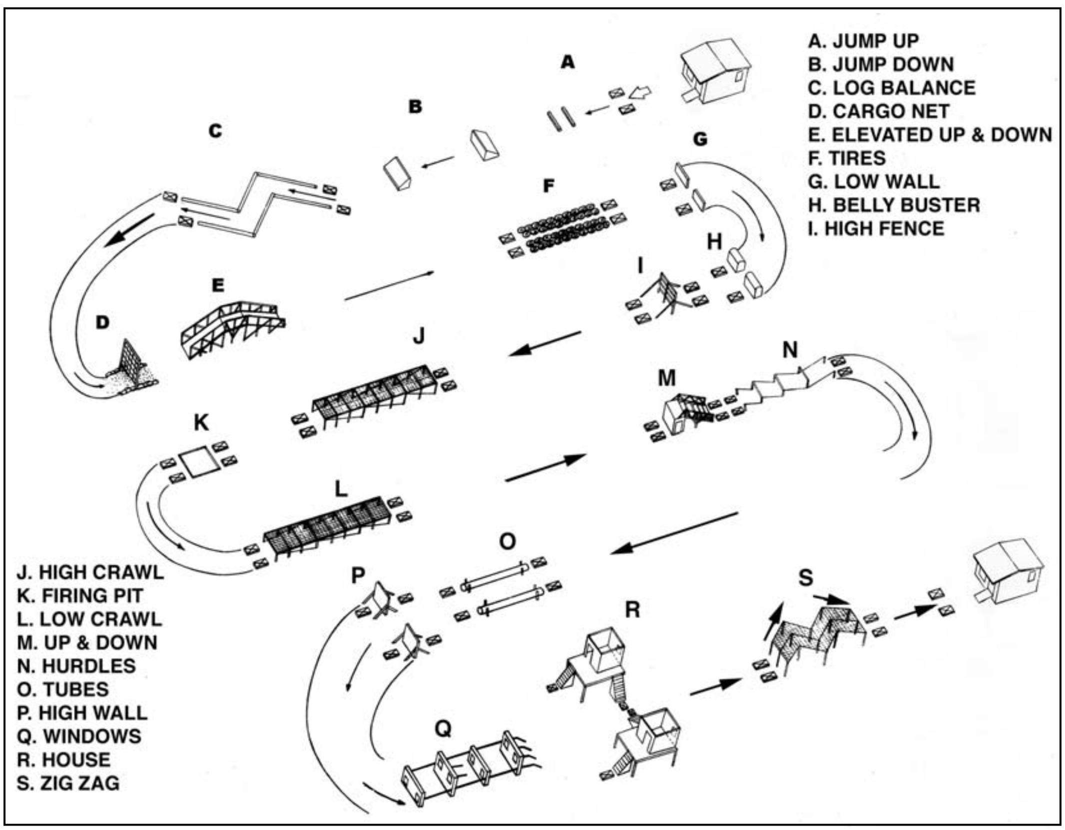

Figure 1. 500-meter mobility-portability course.

Figure 2. Tires

Figure 3. Windows.

Figure 4. High crawl.

3.2.2 Tactile System

The wireless tactile control unit (WTCU) developed by Dr. Lynette Jones at the Massachusetts Institute of Technology (MIT) under the Advanced Decision Architectures Collaborative Technology Alliance (ADA CTA) was used to present tactile signals. The system consists of a tactile display with a receiver unit that was mounted on each participant's body. A wireless control unit is used to control the motors in the tactile array. Each tactor is sealed with glue and then molded in a plastic block 18.4 mm long, 17 mm wide, and 6 mm thick. The plastic encasement makes the motor more robust and increases the contact area between the motor and the skin. The tactors produce a vibration that is similar to a pager or cell phone vibrating. For this experiment, two tactile display configurations were used: a 4x4 array that was mounted on a stretch fabric (used for athletic clothing) and fitted comfortably around the lower torso on a waist band (see figure 5), and a belt that contained eight tactors was positioned at the cardinal compass points (see figure 6). The cardinal compass points include north, northeast, east, southeast, south, southwest, west, and northwest. The tactile display is powered by a 9-V battery. Both displays were worn over the participants' undershirts. The 4x4 array display was worn on the lower back, with the tactors positioned on both sides of back to avoid the spine's indentation. The belt display was worn around the participants' lower abdomen, just above their navel.

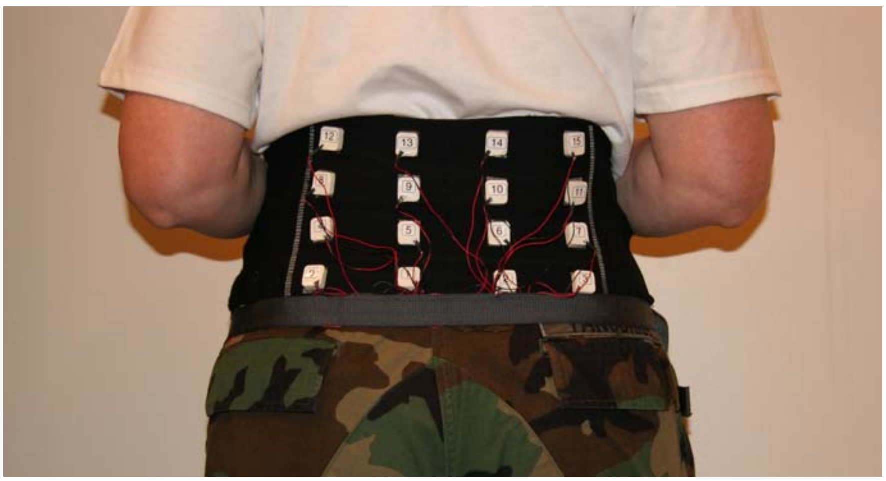

Figure 5. Tactile back configuration.

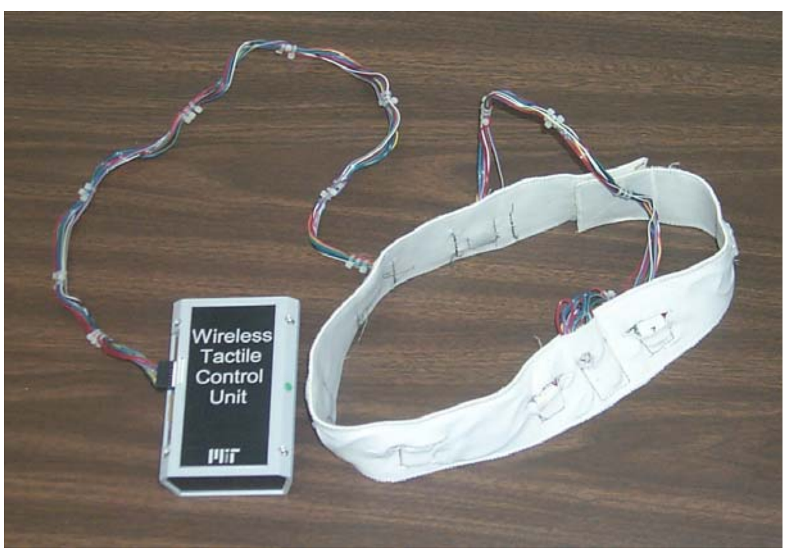

Figure 6. Tactile belt configuration.

3.2.3 Tactile Patterns

Six tactile patterns were created for each display type (see figures 7 and 8). The back display patterns were used in a similar experiment (Jones et al., 2006) and have been demonstrated to have high accuracy in terms of user responses. The belt display patterns were created to be similar in meaning to the back patterns but with fewer tactors. The tactile signals lasted about 2 seconds. The vibrations and the inter-stimulus intervals are outlined in table 1. Participants received the tactile patterns while performing three of the obstacles on the mobility-portability course.

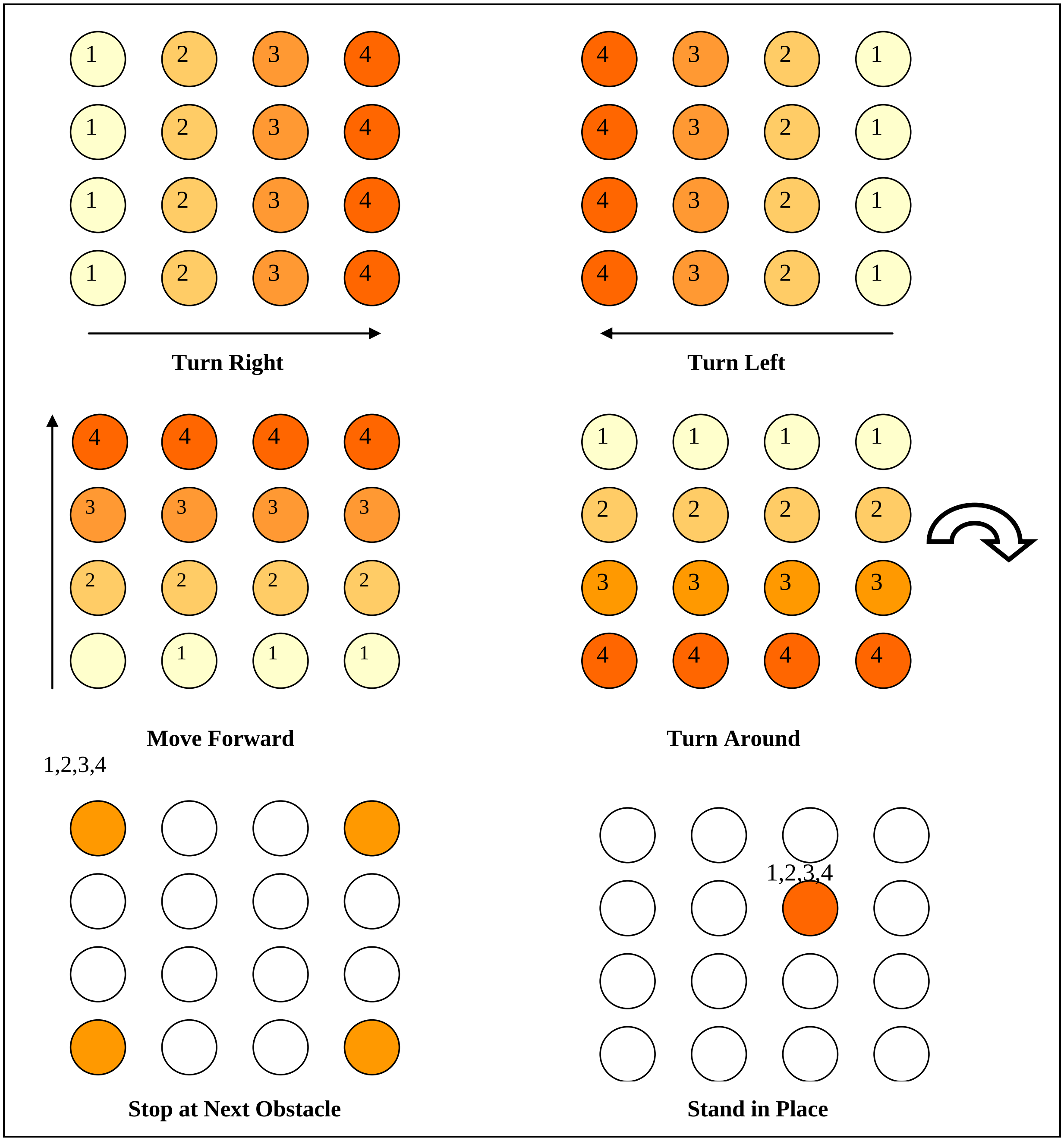

Figure 7. Back display patterns (numbers represent the sequence of activation).

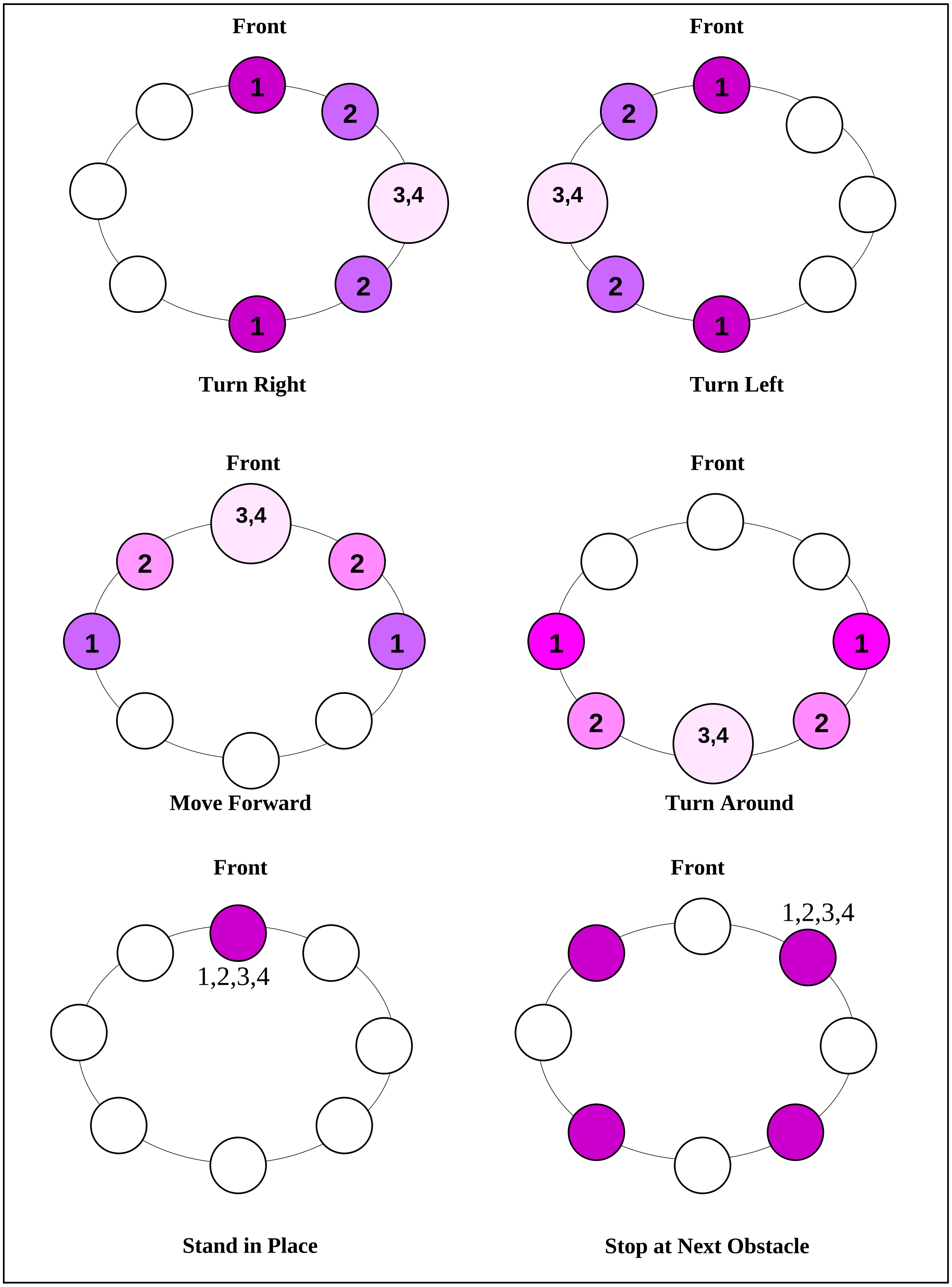

Figure 8. Belt display patterns (numbers represent the sequence of activation).

Table 1. Signal durations.

Signal	Active	Delay	Active	Delay	Active	Delay	Active	Total
Turn Right	0.5		0.5		0.5		0.5	2
Turn Left	0.5		0.5		0.5		0.5	2
Move Forward	0.5		0.5		0.5		0.5	2
Turn Around	0.5		0.5		0.5		0.5	2
Stop at Next Obstacle	0.4	0.2	0.4	0.2	0.4	0.2	0.4	2.2
Stand In Place	0.5	0.1	0.5	0.1	0.5	0.1	0.5	2.3

3.2.4 Soldier Equipment

The Soldiers completed this assessment while wearing a standard fighting load and interceptor body armor (IBA) with SAPI plates, as detailed in table 2. They carried a training device simulating the M4 carbine as they completed the obstacles on the obstacle course. The standard fighting load weighed 37.90 lb.

The IBA consists of an outer tactical vest (OTV) with front and rear SAPI plates. The weights for each component are shown in table 3. Soldiers did not wear deltoid auxiliary protection or side plate inserts for this experiment.

Table 2. Standard fighting load.

Item Description
Underclothing and socks
Battle dress uniform (BDU)
Belt with buckle
Boots
Army combat helmet
Canteen with cover, and 1 quart of water (two-each)
Hand grenades (two-each inert)
Individual first aid kit
Ammunition pouches (two)
M4 carbine mockup

Table 3. IBA component weights (lb).

Size	OTV	SAPI	SAPI x 2	Total
Small	6.95	4.75	9.50	16.45
Medium	7.66	5.45	10.90	18.56
Large	8.38	6.25	12.50	20.88
X-Large	9.51	7.10	14.20	23.71

3.3 Experimental Design

3.3.1 Independent Variables

The experimental design was a mixed design with three independent variables (see table 4). The presentation order for the type of equipment configuration was counterbalanced (see table 5). Order of obstacles was randomly determined.

3.3.2 Dependent Variables

The dependent variables were the percentage of tactile patterns detected, percentage of correctly identified patterns (calculated with the percentage of tactile patterns detected), and response time to detect and identify patterns.

Table 4. Independent variables.

Independent Variable	Levels	Type
Equipment configuration	1. BDU + fighting load 2. BDU + fighting load +IBA	Within subjects
Obstacle	1. Baseline 2. Tires 3. High Crawl 4. Windows	Within subjects
Tactile display	1. Belt 2. Back	Between subjects

Table 5. Equipment presentation order.

Participant	Obstacle 1	Obstacle 2	Obstacle 3
1 (Belt)	A,B	B,A	A,B
2 (Back)	B,A,	A,B	B,A
3 (Belt)	A,B	B,A	A,B
4 (Back)	B,A,	A,B	B,A
5 (Belt)	A,B	B,A	A,B
6 (Back)	B,A,	A,B	B,A
7 (Belt)	A,B	B,A	A,B
8 (Back)	B,A,	A,B	B,A
9 (Belt)	A,B	B,A	A,B
10 (Back)	B,A,	A,B	B,A

A = BDU + load + IBA
B = BDU + load

3.4 Procedures

Before beginning the experiment, each participant completed a volunteer affidavit and received a short briefing about the experimental purpose, procedures, and equipment. Following the orientation, participants completed a training session which consisted of two phases. In the first phase, participants were introduced to the specific obstacles that were used during the experiment and were given the opportunity to negotiate each obstacle to ensure that they understood the proper techniques involved. In the second phase, participants were given a paper copy of the back or belt tactile patterns and received a brief explanation of the tactile patterns they would receive during the experiment. Next, participants were given random tactile patterns and were asked to verbalize which tactile pattern they received (e.g., say “turn right”). Participants were corrected if errors were made. The training session lasted approximately 10 minutes for each participant. Once the participants had a clear understanding of the patterns (i.e., reached 100% accuracy), the experiment began.

During the experiment, each participant donned the back or belt tactile systems and an equipment ensemble (see table 4). Next, participants completed the baseline condition for each equipment configuration. In the baseline condition, participants received tactile patterns while standing still and verbally indicated which pattern they received. The participants then began the moving conditions. Participants received 12 tactile patterns as they moved through each obstacle and verbally indicated which pattern they received. Each participant completed six runs through the windows, six runs through the tires, and four runs through the high crawl. The total time to complete the experiment was approximately 2 hours.

3.5 Data Analysis

Separate mixed model analyses of variance (ANOVA) were conducted on the percent detected, percent correct, and response time data. Equipment configuration, obstacle, and tactile display were the independent variables for all analyses. Statistical significance was concluded when $p < 0.05$. Significant effects were examined *post hoc* with the least significant difference (LSD) test.

4. Results

4.1 Baseline Data

4.1.1 Percent Detected

Participants detected 100% of the tactile patterns during the baseline trials.

4.1.2 Percent Correct

Participants correctly identified 100% of the tactile patterns during the baseline trials.

4.1.3 Response Time

No significant differences in response time were found for the baseline trials $F(1, 8) = 3.78$, $p = .0877$.

4.2 Obstacle Data

4.2.1 Percent Detected

Analysis of the data showed that the obstacles had a significant effect on the detection of tactile signals, $F(2, 32) = 10.23$, $p = .0004$. *Post hoc* tests revealed a significantly lower percentage of signals detected during the high crawl than during the tires and windows (see figure 9). No equipment, display, or any factor interaction effects were significant.

4.2.2 Percent Correct

Analysis of the data showed that the obstacles had a significant effect on the identification of tactile signals, $F(2, 32) = 16.93$, $p < .0001$. *Post hoc* tests revealed a significantly lower percentage of identified signals during the high crawl than during the tires and windows (see figure 10). No equipment, display, or any factor interaction effects were significant.

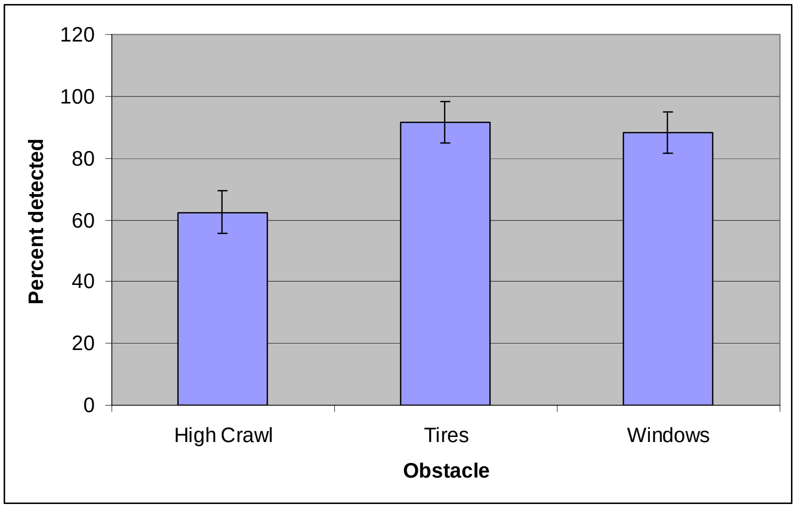

Figure 9. Mean percent detected by obstacle.

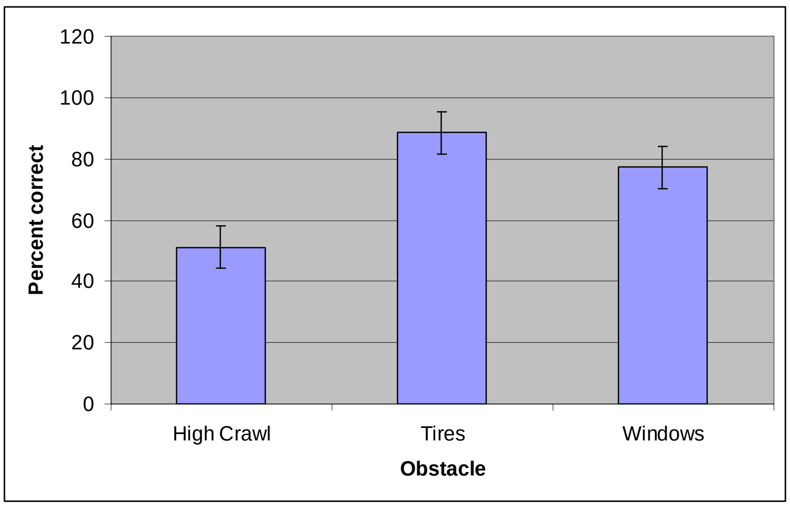

Figure 10. Mean percent correct by obstacle.

4.2.3 Response time

No significant effects on response time were found.

4.3 Tactile Patterns

A brief examination of the pattern data was performed to identify if there were any patterns that resulted in poorer performance (see figure 11). Turn right and turn left resulted in the best performance and stop was the pattern with the worst performance.

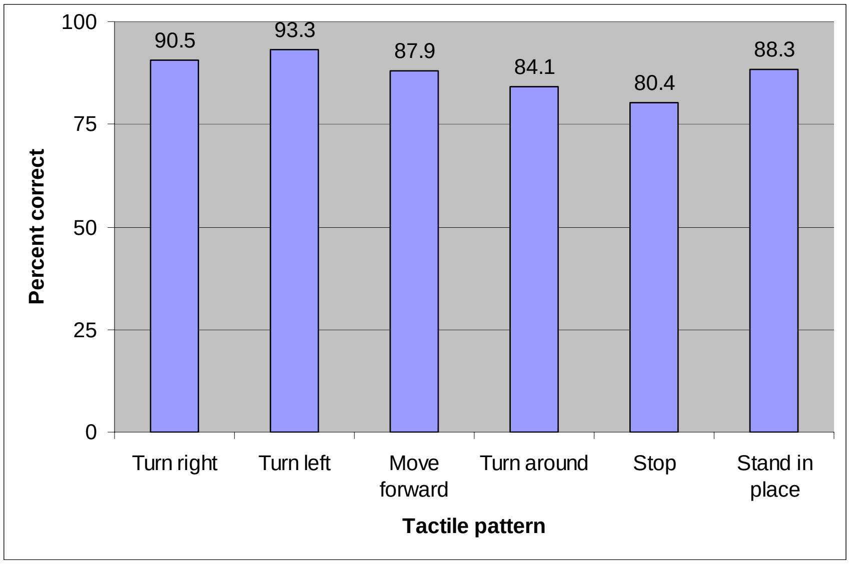

Figure 11. Percent correct identification for each pattern.

5. Discussion and Conclusions

One of the challenges in designing tactile displays is ensuring that the user reliably perceives the signals, even when s/he may be engaged in other mentally or physically demanding tasks. The present study investigated how tactile display configuration and physically demanding tasks (i.e., combat assault maneuvers) affect the detection and recognition of tactile patterns. Participants received six tactile patterns while maneuvering through the high crawl, tires, and windows. The type of tactile display (belt and back) did not affect detection and identification of the tactile patterns. Wearing the body armor with SAPI plates did not affect performance either. It was hypothesized that performance with the back display would be superior to that with the belt display because there were more tactors on the display, allowing for a greater degree of redundancy in the patterns. Furthermore, we expected that the additional weight from the body armor with plates would press on the tactors and make it difficult for the participants to feel the vibrations. However, the data from the present study do not support these assumptions.

With respect to the detection and identification of tactile patterns, baseline data indicated that participants detected and correctly identified 100% of the patterns, with no differences in response time. For the experimental data, participants detected 62.5% of the tactile patterns during the high crawl, which was significantly lower than the tires and windows, with 92% and 88% of signals detected, respectively. With regard to the correct identification of tactile patterns, participants correctly identified 51% of the patterns during the high crawl, as compared to 88.5% for the tires and 77% for the windows. Jones et al. (2006) performed a similar study using tactile patterns as a navigation aid. In their study, eight tactile navigation patterns were presented to participants via a torso-mounted 4x4 tactile array. Participants were able to recognize the patterns with almost perfect accuracy in a laboratory setting and while navigating through a predetermined course in a parking lot. Performance in the present study was evaluated during more challenging field conditions, in which the detection and accurate identification of the tactile signals proved more difficult. Performance with the tires and windows was somewhat degraded, and further research is needed to determine what pattern parameters can be modified to increase the accuracy to an acceptable level, especially when we consider that tactile displays may be relaying valuable information (i.e., navigation, communication) to the Soldier.

Of the six patterns presented, turn left and turn right resulted in the best performance with 93.3% and 90.5% correctly identified, respectively, followed by stand in place (88.3%), move forward (87.9%), and turn around (84.1%). Stop at next obstacle resulted in the worst performance with 80.4% identification. The differences between the tactile pattern with the highest and lowest correct identifications were rather small (only 13%). Futhermore, all identification rates were above 80%, which demonstrates the ability of tactors to communicate several different meaningful patterns to the user. Additional work is necessary to determine if changing the signal characteristics (i.e., location of tactor firing, duration of signal, and number of tactors firing simultaneously) would ensure correct identification of a larger percentage of patterns.

In summary, the results of the present study provide additional insight into the factors that affect tactile pattern recognition. Future work should investigate the benefits of increasing the signal strength and determining how modifying the parameters and configuration of the tactile patterns affects detection and identification.

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